

Comparing the Accuracy of Digital Subtraction Angiography, CT Angiography and MR Angiography at Estimating the Volume of Cerebral Aneurysms

M. HANLEY, W.J. ZENZEN, M.D. BROWN, J.R. GAUGHEN, A.J. EVANS

The University of Virginia Health Systems, Charlottesville, VA, USA

Key words: intracranial aneurysm, cerebral angiography, volume measurement

Summary

While there are many studies that compare imaging modalities in the detection of cerebral aneurysms there are no existing studies that compare two dimensional digital subtraction angiography (DSA), CT angiography (CTA) and MR angiography (MRA) in calculating the volume of cerebral aneurysms. This study will compare these imaging modalities on seven in-vitro models of known volume.

Seven silicone models of cerebral aneurysms were chosen representing slight variations in geometric shape and size. The volume of each model was measured by weighing the amount of water required to fill the aneurysm to the parent artery. Contrast enhanced images of the models were taken with DSA, CTA and MRA. The images were interpreted by four independent readers and the volumes were calculated. The measured volumes from the water weight analysis were compared to the volumes calculated from the interpreter's measurements. The accuracy of DSA, CTA and MRA were compared using the percent of absolute and true variance from the measured volume.

The average percent absolute variance for DSA was 14.3%, CTA was 16.8% and MRA was 18.6%. While these differences were minimal, comparing the percent of true variance demonstrated an average variance of -1.9% for DSA, 16.1% for CTA and -15.9% for MRA.

Calculating the volume of cerebral aneurysms, while increasingly important, is difficult and error prone. It is important to understand the limitations and inherent errors before relying on calculated volumes in clinical decision-making. Regardless of imaging modality, one should consider error rates of 14-19% for calculating volume while keeping in mind the tendency for CTA to overestimate volume, MRA to underestimate volume and DSA to both under and overestimate equally.

Introduction

With recent advances in endovascular aneurysm repair, the accuracy of measuring cerebral aneurysm volume has become increasingly important. Calculating the percent packing volume after coil embolization can be used as an indicator of long-term success and depends on an accurate calculation of aneurysm volume^{1,2}.

Tamatani et Al¹ have shown a relationship between the percent packing volume and recanalization of aneurysms. They found that the incidence of recanalization was significantly lower in aneurysms packed greater than 25%.

Sluzewski et Al² have shown a relationship between compaction of the coil mesh and percent packing volume. They reported no compaction at six months in aneurysms that were packed greater than 24%.

Piotin et Al³ compared rotational DSA, CTA

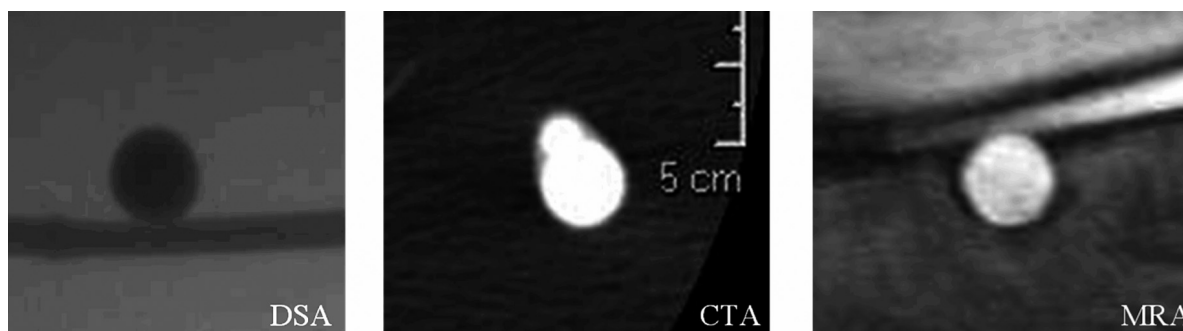


Figure 1 DSA, CTA and MRA images of one of the seven models.

and MRA in a single in-vitro cerebral aneurysm model. They found CTA to be significantly more accurate than MRA ($p=0.0019$) and rotational DSA to be more accurate than CTA ($p=0.1605$), although this did not reach statistical significance. Rotational DSA was found to be significantly more accurate than MRA ($p<0.00001$). Our study compared two-dimensional DSA, CTA and MRA in calculating the volume of seven different in-vitro cerebral aneurysm models with known volumes.

Material and Methods

Seven silicone models were created from images of actual cerebral aneurysms using a wax mold technique. They ranged in size from approximately 4 to 11 mm in diameter and 4 to 12 mm in height as measured by digital calipers during production. The neck width ranged from 2 to 8 mm. The aneurysms were mounted on silicone tubing with an inner diameter of approximately 5 mm. The wall thickness allowed for pulsatility and vessel elasticity.

Table 1 Volume measurements by water weight.

Model	Vol. 1 (mL)	Vol. 2 (mL)	Vol. 3 (mL)	Average (mL)
1	0.035	0.044	0.039	0.039 (± 0.004)
2	0.140	0.142	0.136	0.139 (± 0.003)
3	0.267	0.263	0.267	0.266 (± 0.002)
4	0.294	0.312	0.306	0.304 (± 0.009)
5	0.286	0.284	0.290	0.287 (± 0.003)
6	0.449	0.451	0.453	0.451 (± 0.002)
7	0.525	0.526	0.525	0.525 (± 0.001)

The true volumes of the models were measured by water weight analysis. Approximately 2 mL of water was placed in a dish on a scientific scale and tared (Mettler Toledo AX2). A 1 mL syringe with a microcatheter cut to approximately 10 cm was used to draw up water. The catheter was advanced into the aneurysm with the aneurysm neck facing down. The aneurysm was carefully filled with water to the level of the parent artery. The remaining water was returned to the dish. The difference in water weight equaled the volume of the aneurysm. The aneurysm was dried and this was repeated three times for all seven models.

The following steps were performed similarly for all three imaging modalities. The models were connected in series with vinyl tubing and placed in a plastic container filled with water. The models were connected to a pulsatile flow pump running at 60 bpm with an output of approximately 60 mL per minute, corresponding to a stroke volume of 1 mL. Contrast agent was added to the circulating water in order to opacify the models. Air was removed from the system before imaging. The models were cleaned and dried between experiments.

For the DSA experiment, the models were placed on a Siemens Axiom Artis Biplane Angiography system (Erlangen Germany). The aneurysms were positioned perpendicular to the beam (figure 1). With the pump running, 120 mL of Gastroview contrast was added to a reservoir of approximately 800 mL of water. Images were acquired in two runs to capture all of the models. The images were calibrated to correct for the known distance from the aneurysms to the table. A 7 mm bead was placed in the field to verify calibration.

For the CTA experiment, the models were placed on a 16 slice GE Lightspeed scanner

(GE Healthcare, United Kingdom). Images were acquired perpendicular to the long axis of the parent vessel (figure 1) with 400 mL of Gastroview and 50 mL of Omnipaque circulating through the models.

For the MRA experiment, the models were placed in a CP Head Array Coil on a Siemens 1.5T Sonata Platform (Erlangen Germany). The pump circulated 10 mL of Gadolinium in 5 L of water. The 3D Time of Flight images were acquired parallel to the long axis of the parent vessel (figure 1).

Four independent readers measured the aneurysms using all three modalities. DSA images were measured on a calibrated workstation with similar magnification among readers. CTA and MRA images were read on a PACS workstation under similar magnification and windowing among readers (CT in vascular windows C:150 and W:550, MR in 3D TOF). Windowing was adjusted to simulate actual studies. Readers were blinded to aneurysm size, measured volume, and to each other's measurements.

For all of the images, the diameter and height were measured on a single image in which the aneurysm appeared the largest. The edge of the aneurysm was determined subjectively. The windowing was consistent between readers. The height was measured from the parent artery to the point furthest from the parent artery (figure 2).

The diameter was taken at the widest point perpendicular to the height. Volume was calculated using the formula for an ellipsoid with the diameter squared (figure 3). Calculations were repeated using the online cerebral aneurysm

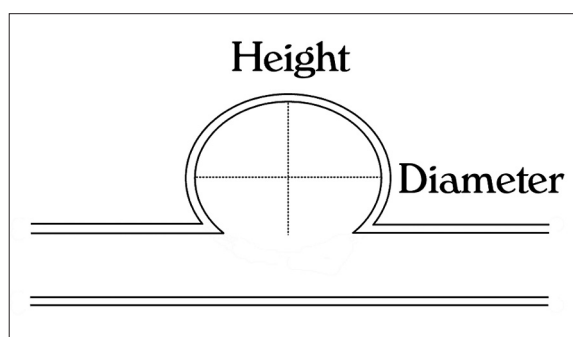


Figure 2 Height was measured from the parent artery to the point furthest from the parent artery. Diameter was measured at the widest point perpendicular to the height.

$$\text{Volume} = \frac{h (\text{Diameter})^2 (\text{Height})}{6}$$

Figure 3 Formula for an ellipsoid adapted for a two dimensional measurement with diameter squared.

$$\% \text{ Variance} = \frac{[(\text{Known Volume}) - (\text{Calculated Volume})]}{\text{Known Volume}}$$

Figure 4 Formula for percent variance with the known volume being that measured by water weight analysis.

calculator found at www.AngioCalc.com.

The calculated volumes were compared to the volumes obtained from the water weight analysis by percent of absolute variance (figure 4). We believe that this method of comparison best represents the accuracy of these imaging modalities for a single measurement, mimicking clinical practice.

Table 2A Average absolute variance in volume averaged for an individual reader.

	DSA (%)	CTA (%)	MRA (%)	Average
Reader One	21.6	13.8	19.6	18.3
Reader Two	18.0	29.4	19.5	22.3
Reader Three	16.2	10.7	23.4	16.8
Reader Four	19.9	17.4	29.5	22.3
Average Absolute Variance	18.9 (+ 2.3)	17.8 (+ 8.3)	23.0 (+ 4.7)	
*Differences between Tables 2 and 3 result from averaging a single reader's variance vs. averaging a single model's volume.				

Table 2B Average true variance in volume averaged for an individual reader.

	DSA (%)	CTA (%)	MRA (%)
Reader One	-16.1	13.8	-12.8
Reader Two	-10.1	29.2	-14.1
Reader Three	7.7	6.6	-7.0
Reader Four	10.8	14.7	-29.5
Average True Variance (p=0.008)	-1.9	16.1	-15.9
*Differences between Tables 2 and 3 result from averaging a single reader's variance vs. averaging a single model's volume.			

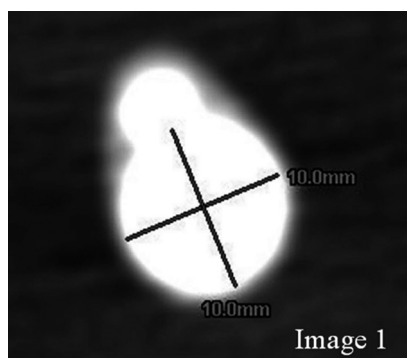
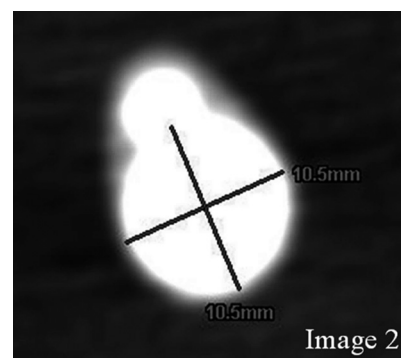


Figure 5 Images from a PACS workstation showing small variation in two dimensional measurements.



Results

The volume of each the seven models was successfully measured by water weight analysis (table 1) with an average standard deviation of 0.003 mL (range 0.001-0.009 mL). Both the absolute and true variance was used to compare the imaging modalities.

The absolute variance ignores whether the calculated volume is above or below the measured volume while the true variance is best used to demonstrate if an imaging modality over or underestimates volume.

The percent of absolute and true variance was calculated for each reader for all three modalities. Each reader's percent of absolute variance was averaged for all seven models

(Table 2A). On average, the readers performed similarly. Averaging the reader's percent of absolute and true variation (tables 2A and 2B) is felt to be less accurate than averaging their volume calculations (table 3), but it was included for comparison.

The differences in tables 2 and 3 result from averaging a single reader's variance versus averaging a single model's volume.

The percent of absolute and true variance was calculated for each model for all three imaging modalities. The average percent absolute variance for DSA was 14.3%, CTA was 16.8% and MRA was 18.6%. Comparing the percent of true variance demonstrated an average variance of -1.9% for DSA, 16.1% for CTA and -15.9% for MRA ($p=0.03$).

Table 3 Average absolute and true variance in volume calculated from averaged volumes.

	DSA (%)	CTA (%)	MRA (%)
Model One	-11.4	56.9	-19.7
Model Two	-3.23	29.4	-24.7
Model Three	-28.3	9.63	-52.3
Model Four	-13.7	-2.49	-24.0
Model Five	1.08	2.65	2.06
Model Six	6.26	7.64	0.77
Model Seven	35.8	8.82	6.92
Average Absolute Variance	14.3 (+ 13.1)	16.8 (+ 19.9)	18.6 (+ 18.0)
Average True Variance ($p=0.030$)	-1.9	16.1	-15.9

**Differences between Tables 2 and 3 result from averaging a single reader's variance vs. averaging a single model's volume.*

Discussion

With advances in endovascular aneurysm repair, the accuracy of measuring cerebral aneurysm volume has become increasingly important. Accurately measuring aneurysm volume is essential in calculating percent packing volume after coil embolization, not simply as an academic exercise, but as a long term prognostic indicator¹⁻². Additionally, volume measurements could become more important in the growing use of liquid embolic polymers. However, before volume calculations can be relied upon clinically, we must be mindful of their accuracy and precision.

Initially, we were interested in why all three modalities were subject to error rates of 14-19%. We started by looking at the mathematics involved in measuring volume and were able to appreciate how small errors in a single measurement can result in large errors in volume. This principal is illustrated in figure 5 and table 4, where a 5% error in diameter and height results in a 15.8% variance in volume, based on the formula for an ellipsoid.

While the difference between the percent of absolute variance for DSA, CTA and MRA was minimal, much can be gained from further analysis. The results in table 3 suggest that CTA overestimates volume, MRA underestimates volume and DSA both over and underestimates volume equally. Of the multiple variables that could result in this variance, we suspect proper windowing could account for a portion of this variance and we are currently investigating this further. Interestingly, other investigators have found similar results. Piotin et Al.³ showed 3D DSA to overestimate by 7%, CTA to overestimate by 11.3% and MRA to underestimate by 15%.

In 2006, Piotin et Al.⁴ demonstrated the inferiority of ellipsoid approximations when compared to 3D rotational angiography (3D RA). This difference was most notable in irregularly shaped aneurysms. While 3D RA is more accurate, not every facility has this imaging capability and even those that do have 3D RA do not use it for every procedure.

Conclusions

With the increasing importance of measuring cerebral aneurysm volume, it is critical to appreciate the limitations of these calculations

Table 4 **Illustration of small error resulting in large percent variance.**

	Diameter (mm)	Height (mm)	Volume (mL)
Image 1	10.0	10.0	0.524
Image 2	10.5	10.5	0.606
	Variance		15.8% (0.083 mL)

and to be aware of the inherent errors that accompany them. Regardless of imaging modality, one should consider error rates of 14-19% for calculating volume while keeping in mind the tendency for CTA to overestimate volume, MRA to underestimate volume and DSA to both under and overestimate equally. Further work in computer assisted measurements and accurate windowing techniques will hopefully reduce these errors and reinforce their clinical importance.

References

- 1 Tamatani S, Ito Y et Al: Evaluation of the stability of aneurysms after embolization using detachable coils: Correlation between stability of aneurysms and embolized volume of aneurysms. *Am J Neuroradiol* 23: 762-767, 2002.
- 2 Sluzewski M, Willem JvR et Al: Relation between aneurysm volume, packing, and compaction in 145 cerebral aneurysms treated with coils. *Radiology* 231: 653-658, 2004.
- 3 Piotin M, Gailloud P et Al: CT angiography, MR angiography and rotational digital subtraction angiography for volumetric assessment of intracranial aneurysms. An experimental study. *Neuroradiology* 45: 404-409, 2003.
- 4 Piotin M, Daghighian B et Al: Ellipsoid approximation versus 3D rotational angiography in the volumetric assessment of intracranial aneurysms. *Am J Neuroradiol* 27(4): 839-842, 2006.

Michael Hanley, MD
1411 Oaklanding Road
Mount Pleasant, SC 29464
USA
(843) 971-7157
hanley@musc.edu